In commemorating IDNDR

JSCE
Osaka 1991

International Symposium on
Natural Disaster Reduction and Civil Engineering

CHARACTERISTICS OF THE JULY 1990 PHILIPPINE EARTHQUAKE AND RELATED DAMAGES

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SUMMARY

The Philippine earthquake of 1990 caused severe loss to life and property. Because of its great effects the study of its characteristics and its use in seismic design provisions would be very valuable. Unfortunately, no strong motion record was taken during the main shock. By identifying the characteristics of this earthquake and the related damages, we can also characterize the accompanying ground motion. Based on these characteristics, the direction of further study may be identified.

1. INTRODUCTION

Last July 16, 1990 at 16:26H (DST) local time, a devastating earthquake struck the Central Luzon area of the Philippines. Its magnitude was measured at 7.8 on the Richter scale. The epicenter was located at 15.664°N and 121.247°E. The Philippine Institute of Volcanology and Seismology (PHILVOCS) placed the hypocenter at a depth of 28 km [1]. The effects of this earthquake spanned a wide range of area and resulted in several types of earthquake hazards. The earthquake and its resulting destruction to lives and property reaffirmed that the Philippines is a seismically active area.

This paper aims to identify the characteristics of this earthquake in terms of the properties of the ground motion. This is important because there were no strong motion records taken during the main shock. To be able to have a more rational seismic design provisions, there is a need to estimate the amount of ground shaking that the structures are expected to withstand.

The ground motion will be characterized by: (1) description of the activated fault and observations at or near the fault during the tremor; (2) discussion of the isoseismal maps developed for this earthquake; (3) discussion of attenuation laws appropriate for the Philippines; (4) observation of aftershocks; (5) highlights of observed damages; (6) field study of fallen objects in the felt areas; and (7) analysis of expected peak ground acceleration using earthquake history data and assumed attenuation law.

2. ACTIVATED FAULT

PHILVOCS identified and mapped several earthquake generators in the Philippines. Plots of epicenters of past earthquakes show that most active earthquake generators are the subduction zones in the eastern part of the country. Another significant feature is the Philippine Fault Zone (PFZ) which runs from north to south which visually forms the "backbone" of the archipelago (Figure 1).

Historically, the PFZ has contributed much of the destructive earthquakes in the Philippines (Figure 2).

The activated fault for this earthquake is part of the northern portion of the PFZ and one of its splays.

The surface rupture of the activated fault trends NW and SE and about 125 kilometers long. The movement along the surface rupture is predominantly left-lateral strike-slip. Horizontal offset range from 1 to 6 meters while vertical offsets average less than 1 meter [1].

2.1 Observations of residents near the activated fault

Residents living near the site of the activated fault reported hearing loud sounds similar to thunder or a big rolling boulder less than a minute before the ground shaking. Residents also described the ground shaking as very violent. The people found it hard to keep their balance and most were unable to stand during the shaking.

2.2 Damage near the activated fault zone

Damage to structures situated along the activated fault zone was very minimal, except for those which were situated exactly on the surface rupture. Structures consists of traditional dwellings made from wood and a few were of reinforced concrete. Since the area of the fault zone is mostly rural, high and medium rise buildings are rare.

A number of landslides and rockslides occurred along the Cagayan Valley Road (a portion of the Pan-Philippine Highway). The activated fault cut across the road at several points. These numerous landslides probably resulted from large accelerations generally experienced at the site of ground ruptures.

3. INTENSITY OBSERVATIONS

Strong motion records are normally used to determine the amount of shaking caused by the earthquake. Since no strong motion record of the main shock of this earthquake was taken, the intensity of the ground motion could be used to estimate the maximum peak ground acceleration (PGA).

As in past destructive earthquakes, the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) generated an isoseismal map (Figure 3) for this earthquake [2].

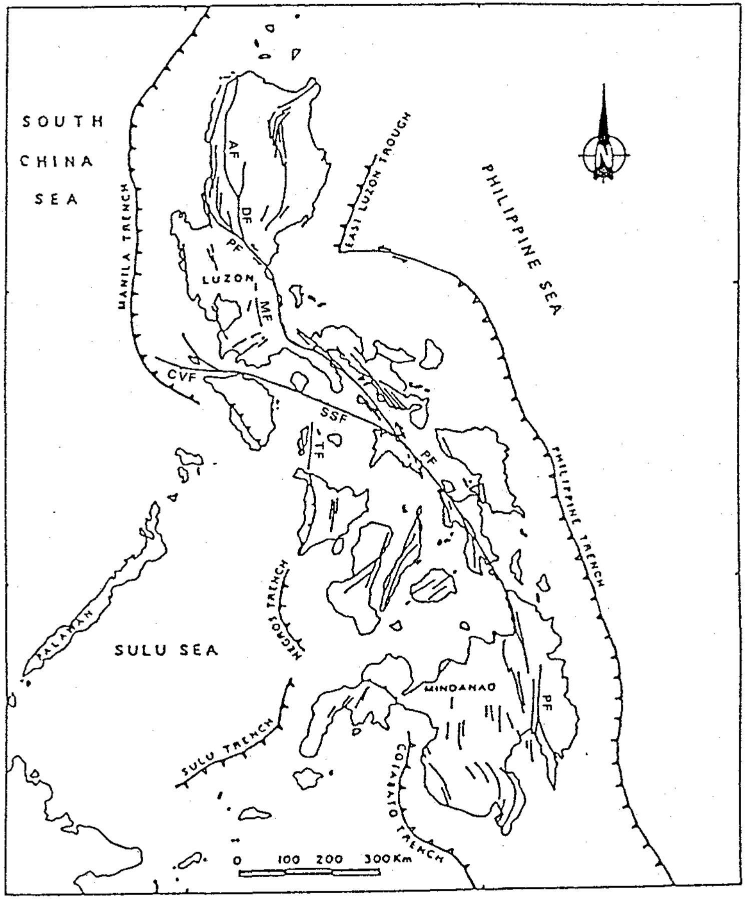


Figure 1 Map of known earthquake generators in the Philippines [1] (Legend : PF = Philippine Fault , DF = Digdig Fault , AF = Abra Fault , MF = Marikina Fault , SSF = Sibuyan Sea Fault , CVF = Cape Verde Passage Fault , TF = Tablas Fault)

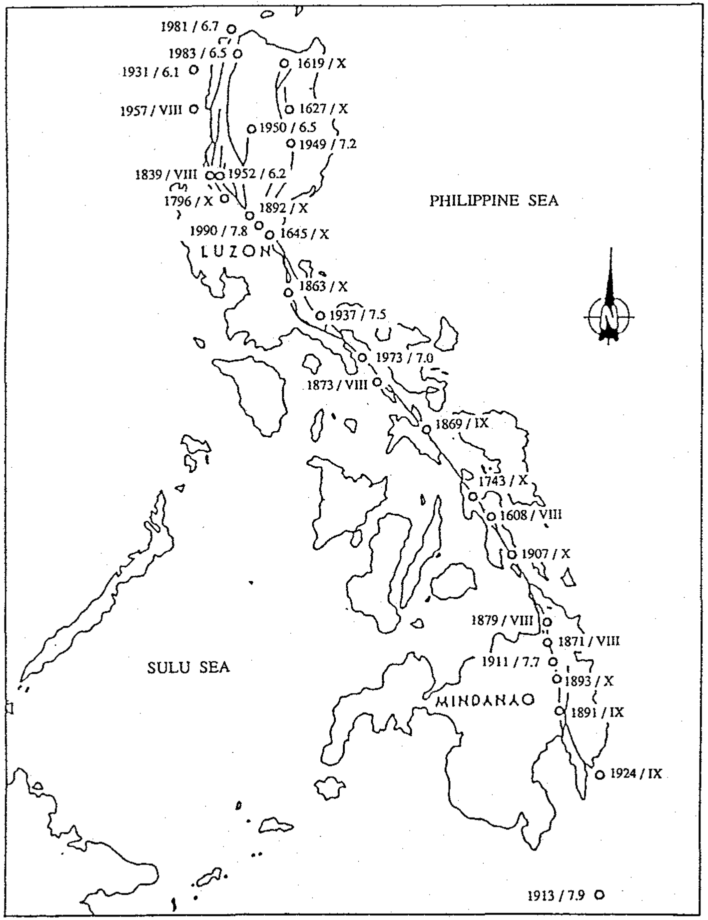


Figure 2 Map of destructive earthquakes along Philippine Fault Zone [1] (Arabic and Roman Numerals after the year refer to magnitude and intensity respectively)

The intensity scale used in the Philippines is the Philippine Rossi-Forel scale with an intensity range of I to IX. Table 1 lists the description of the Rossi-Forel scale as adopted in the Philippines. The correlation of the Rossi-Forel scale to the Modified Mercalli scale is given in Table 2 based on comparison of descriptions [4]. The two scales are somewhat similar except for the high ranks. Correlations between intensity and accelerations have been developed but these should not be used directly for design. The correlation of the Modified Mercalli scale with the maximum acceleration (or PGA) is given in Table 3 as proposed by the United States Coast and Geological Survey (USCGS) [5].

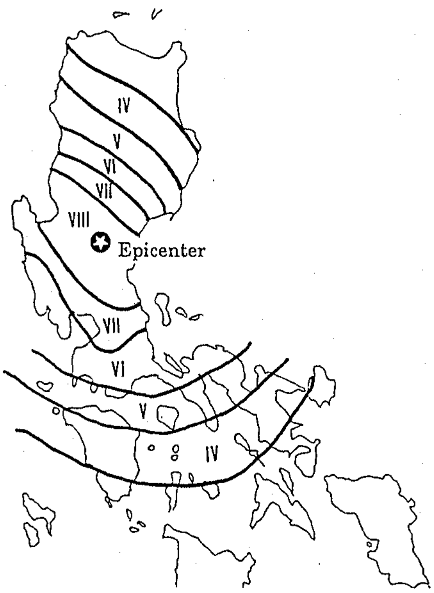


Figure 3 Isoseismal map of the 16 July 1990 Philippine Earthquake (Rossi-Forel Intensity Scale)

Table 1 Philippine Rossi-Forel Earthquake Intensity Scale [3]

I.	HARDLY PERCEPTIBLE SHOCK : Felt only by an experienced observer under favorable conditions.
II.	EXTREMELY FEEBLE SHOCK : Felt by small number of persons at rest.
III.	VERY FEEBLE SHOCK : Felt by several persons at rest. Duration and direction may be perceptible. Sometimes dizziness and nausea are experienced.
IV.	FEEBLE SHOCK : Felt generally indoors, outdoors by a few. Hanging objects swing slightly. Cracking of frames of houses.
V.	SHOCK OF MODERATE INTENSITY : Felt generally by everyone. Hanging objects swing freely. Overturn of tall vases and unstable objects. Light sleepers awaken.
VI.	FAIRLY STRONG SHOCK : General awakening of those asleep. Some frightened persons leave their houses. Stopping of pendulum clocks. Oscillation of hanging lamps. Slight damage in very old or poorly built structures, old walls, etc. Some landslides from hills and steep banks. Cracks in road surfaces.
VII.	STRONG SHOCK : Overturn of movable objects. General alarm, all run outdoors. Damage slight in well-built houses, considerable in very old or poorly built structures, old walls, etc. Some landslides from hills and steep banks. Cracks in road surfaces.
VIII.	VERY STRONG SHOCK : People panicky. Trees shaken strongly. Changes in flow of spring and wells. Sand and mud ejected from fissures in soft ground. Small landslides. Slides in river banks.
IX.	EXTREMELY STRONG SHOCK : Panic general. Partial or total destruction of some buildings. Fissures in ground. Landslides and rockfalls.

Table 2 Correlation of Philippine Rossi-Forel Intensity Scale and Modified Mercalli Intensity Scale [3]

Philippine Rossi-Forel Scale	Modified Mercalli Scale
II	II
III	III
IV	IV
V	IV-V
VI	V-VI
VII	VII
VIII	VIII
IX	IX-XII

Table 3 Correlation of Modified Mercalli Intensity Scale and Maximum Acceleration [4]

Modified Mercalli Scale	Maximum Acceleration (gals) [mean in brackets
II	1-5 [2.3]
III	1-8 [3.1]
IV	2-46 [9.3]
V	2-75 [13.3]
VI	5-175 [40]
VII	18-140 [67]
VIII	51-350 [172]
IX	250 [250]

Acharya [3] studied the isoseismal maps of several large past earthquakes published by PAGASA and other researchers and developed an intensity attenuation law for the Philippines. This intensity attenuation law is shown by equation (1).

$$\ln I = \ln(1.5M - 1.5) + 0.327 - 0.13 \ln \Delta - 0.00089 \Delta \quad (1)$$

where I is the intensity in the Philippine Rossi-Forel scale, M is the magnitude in Richter scale, and Δ is the epicentral distance in kilometers.

Figure 4 shows the plot of Acharya's intensity attenuation law. Comparing it with the observed isoseismals in Figure 3, it can be said that Acharya's attenuation law is in agreement with the observed isoseismals for the intensities south of the epicenter and within 100 kilometers north of the epicenter. The attenuation law underestimates the intensity for the rest of northern Luzon.

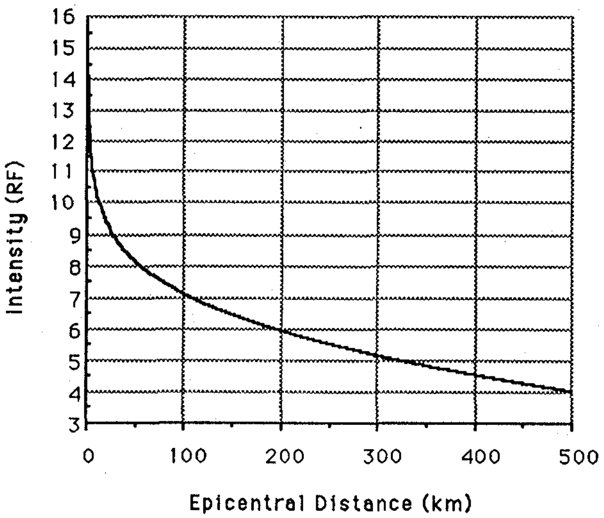


Figure 4 Plot of Acharya's Intensity Attenuation Law

The underestimated region is characterized by mountain ranges as compared to the generally flat plains of the other affected areas.

4. AFTERSHOCK OBSERVATION

A joint team from the U.S. Geological Survey (USGS) and PHILVOCS were able to get digital records of aftershocks of this earthquake [5]. Figure 5 shows the distribution of epicenters of the aftershocks . From this figure, it can be observed that there was clustering of aftershocks on 4 regions, namely: (1) along the surface rupture , (2) near the northern tip of the rupture, (3) west side of the surface rupture near Baguio and La Union, and (4) north of the surface rupture. The largest aftershock, with a magnitude of 6.6, was recorded on July 17, 1990 near the northern tip of the surface rupture [1]. This pattern of aftershock distribution was attributed to: a) presence of still unreleased stress along the rupture trace, b) subsurface crustal readjustment near the termination of the rupture trace to accommodate the large horizontal slip, and c) possible reactivation of other faults or splays of the PFZ in the region but did not result in surface rupture [1].

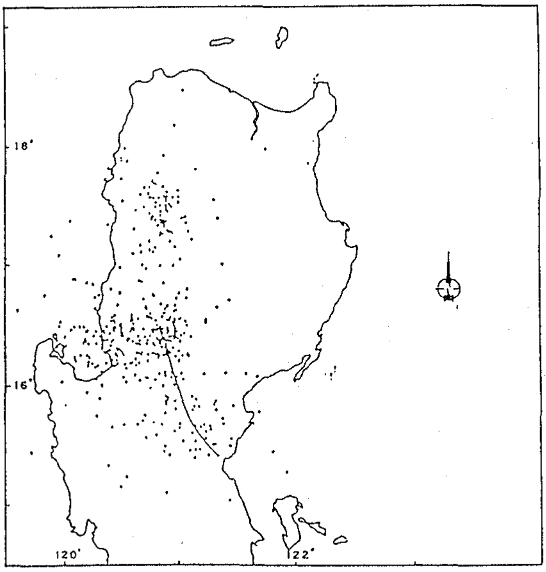


Figure 5 Distribution of aftershock epicenters [1]

5. OBSERVED DAMAGES

Much of the damage due to this earthquake occurred far from the epicentral area. In areas around the epicenter of the earthquake, very minimal damage was observed.

Numerous structural failures and collapses were observed in Baguio and Agoo, La Union. Extensive liquefaction and lateral spreading occurred in Dagupan and in several isolated areas within the Central Luzon area. Numerous bridges were damaged due to the failure of the foundations caused by liquefaction/lateral spreading and large ground motions.

Landslides and rockslides were very extensive near the surface rupture.

5.1 Structural Damage

5.1.1 Baguio City

Several buildings in Baguio collapsed or were severely damaged. From Molas and Yamazaki [6], it was observed that most of these buildings were built on sloping ground and/or have a special configuration that includes large overhangs, abrupt change in storey stiffness, large dissymmetry of torsional rigidity, etc. It was also observed that buildings 5 stories or higher are more susceptible to severe damage, more so for buildings higher than 7 stories. This suggest that the dominant frequency of the earthquake ground motion is near the natural frequen-

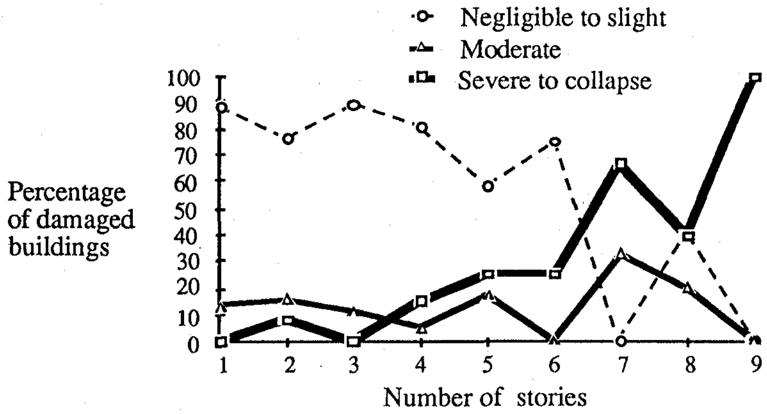


Figure 6 Relation of number of stories to percentage of damage (After Molas and Yamazaki [6])

cy of these buildings. Figure 6 shows the number of stories to percentage of damaged buildings.

Based on the Philippine seismic design code, the natural period of a reinforced concrete building falling under the category of "Ductile Moment Resisting Space Frame" can be estimated by 0.1 N (secs.), where N is the no. of stories. Then 7, 8, and 9 stories would correspond to 0.7, 0.8, and 0.9 secs., respectively. Buildings with elements for resisting lateral forces would be stiffer and thus have a shorter natural period. If resonance played an important factor on the severity of damage in these buildings then it can deduced that the predominant period of the ground motion may be within or close to this range.

5.1.2 Agoo, La Union

It was obvious that the ground shaking in Agoo was very strong judging from the damaged sustained by the structures. Even two-storey wood framed houses were not spared in this small town. Nearer to the sea, extensive liquefaction was reported. One coastal village literally disappeared when it sank about one meter due to liquefaction. Such observations, together with the aftershock distribution near the area, seem to suggest that a fault near the city was activated although no surface manifestation was found.

5.2 Liquefaction / Lateral Spreading

Liquefaction and lateral spreading were reported in several places in Central Luzon [1], but the most extensive damage was in Dagupan City. Several buildings sank by about one meter and/or tilted. One main bridge across the Pantal river collapsed due to the lateral spreading beside the river banks.

5.3 Damage to Bridges

Several bridges in the Central Luzon area collapsed or was otherwise damaged beyond serviceability. Causes of the damage to bridges range are (1) abutment/foundation failure due to liquefaction or lateral spreading; (2) damage to superstructure due to pounding; (3) inadequate restraint for relative displacement of superstructure with respect to the supports; (4) brittle failure of piers due to lateral loads imposed by earthquake.

5.4 Slope Stability

Severe landslides and rockslides occurred at the Cagayan Valley Road in the vicinity of the ground rupture and in the mountain roads of Baguio. Both locations are known landslide-prone areas which experience landslides during heavy rainfall of the monsoon season.

6. FIELD SURVEY

A survey team from the Japan Society of Civil Engineers (JSCE) went to the Philippines to survey the damages due to the earthquake from August 15 to August 22, 1990. One group surveyed the Cabanatuan area and other parts of Nueva Ecija and Rizal to survey the surface ruptures and other damages. One of the tasks of the group was to obtain data regarding the apparent peak ground acceleration that occurred in the area.

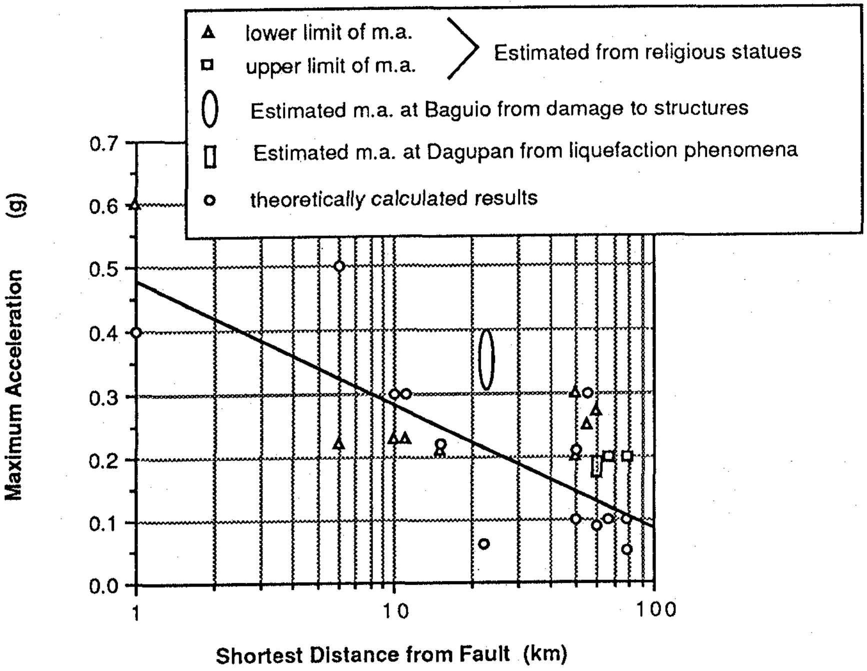


Figure 7 Plot of estimated maximum accelerations during field survey and theoretically calculated results by Sato [7] (Regression line considers theoretical results only, plot was redrawn from [8])

One method that is popular in Japan is to measure the tombstones that were toppled and those that were not. Based on the aspect ratio of the tombstone, an estimate of the PGA can be calculated. Fallen tombstones represent the lower bound of the PGA while the unfallen tombstones represent the upper bound of the PGA. This method is oversimplified but very useful in obtaining rough estimates.

In the Philippines, however, the method of burial is different from Japan and tombstones are not generally used. Therefore, the group searched for similar objects from which to gather data. The objects used were gateposts, furnitures and religious statues. The data interpretation of the group is given in Figure 7.

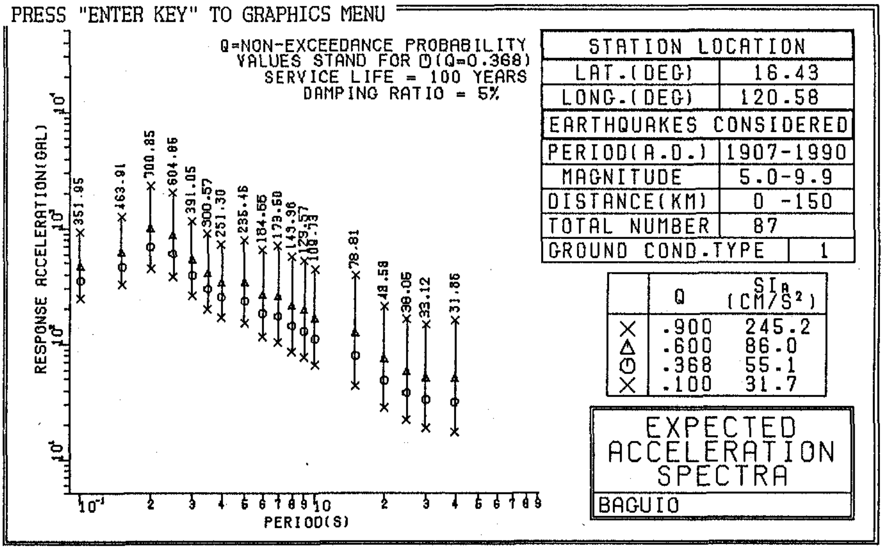
7. ERISA-P ANALYSIS

ERISA-P is an acronym for Earthquake Risk Analysis-Personal Computers. The program uses earthquake history data and given attenuation law to compute for parameters relevant to earthquake risk assessment for a given site [9,10]. These parameters are then displayed in several graphs for better readability. One of these parameters is the expected acceleration spectra for a site (Figure 8). For this analysis, a catalogue of Philippine earthquakes provided by PHILVOCS and McGuire's attenuation law (Eqn. 2) for western United States was used [11] .

$$a = 472 \times 10^{0.28M} (R+25)^{-1.3} \qquad (2)$$

where a = peak ground acceleration, PGA (gals)
M = earthquake magnitude
R = hypocentral distance (km)

Earthquakes whose epicenters were within 150 kilometers from Baguio City and with magnitudes greater than 5 were used in the analysis.



STATION LOCATION	
LAT.(DEG)	16.43
LONG.(DEG)	120.58
EARTHQUAKES CONSIDERED	
PERIOD(A.D.)	1907-1990
MAGNITUDE	5.0-9.9
DISTANCE(KM)	0 -150
TOTAL NUMBER	87
GROUND COND.TYPE	1

	Q	SI_A (CM/S^2)
X	.900	245.2
Δ	.600	86.0
⊖	.368	55.1
X	.100	31.7

EXPECTED
ACCELERATION
SPECTRA
BAGUIO

Figure 8 Expected acceleration response spectra for Baguio City

CONCLUDING REMARKS

For a large destructive earthquake, it is important to know the characteristics of the ground motion to be able to improve seismic design provisions. In the case of the 1990 Philippine earthquake, no strong motion records were taken. In lieu of the strong motion records, the characteristics of the ground motion may be correlated to the observed effects of the earthquake. These include the characteristics of the surface rupture, observed intensities, attenuation laws, aftershock observations, observed damages, field surveys of fallen objects, and seismic risk analysis from historical earthquake data.

Current correlations still have a high degree of uncertainty and research in this area will be most welcome.

Strong motion records at several sites are still the most favored to use in seismic design provisions. Since the Philippines is a highly seismic country, the installation of strong motion instruments is essential to improve the understanding of engineers and seismologist and to mitigate future disasters.

REFERENCES

[1] Punongbayan, R.S. and Umbal, J.V., Overview and Impacts of the July 16, 1990 Luzon Earthquake, Philippine Institute of Volcanology and Seismology (PHILVOCS), (1991)

[2] Report on Expert Team of Japan Disaster Relief Team (JDR) on the Earthquake in Philippines of July 16, 1990, Japan International Cooperative Agency (JICA) , August (1990)

[3] Acharya, H.K. , Ground Motion Attenuation in the Philippines, Proc. 2nd Int'l Conf. on Microzonation for Safer Construction, Vol 1, pp. 379-390 (1978)

[4] Kanai, K. , Engineering Seismology, University of Tokyo Press , (1983)

[5] Philippine Institute of Volcanology and Seismology (PHILVOCS), Philvocs Observer, Volume 6, No. 3, (1990)

[6] Molas, G.L. and Yamazaki, F. , Reconnaissance Report on Structural Damage in Baguio by the July 16, 1990 Luzon Earthquake, Bull. Earthquake Resistant Struc. Res. Center, No. 24, pp. 19-45, Institute of Industrial Science, Univ. of Tokyo, (1990)

[7] Sato, T. , Estimation of Seismic Intensity of Ground Motion During the 16 July 1990 Philippine Earthquake, unpublished report

[8] Japan Society of Civil Engineers (JSCE) Investigation Team, Preliminary Report of JSCE Reconnaissance Team on July 16, 1990 Luzon Earthquake, August, (1990)

[9] Tomatsu, Y and Katayama, T. , <ERISA-G> An Online Graphic System for Earthquake Risk Analysis (Its Development and Computer Programs), Report of the Institute of Industrial Science, The University of Tokyo, Vol. 32, No. 1 , January, 1986 (in Japanese)

[10] Tomatsu, Y., Katayama, T. and Nagata, S. , Development of the <ERISA-P> Seismic Hazard Analysis System for IBM Personal Computers, submitted for publication

[11] Acharya, H.K., Seismic and Tsunamic Risk in the Philippines, Proc. 7th World Conf. on Earthquake Engineering, Vol. 1, pp. 391-394, (1980)